DIRC-based PID for the EIC – Progress Report

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Generic Detector R&D for an Electron Ion Collider

Advisory Committee Meeting, BNL, May 17, 2012

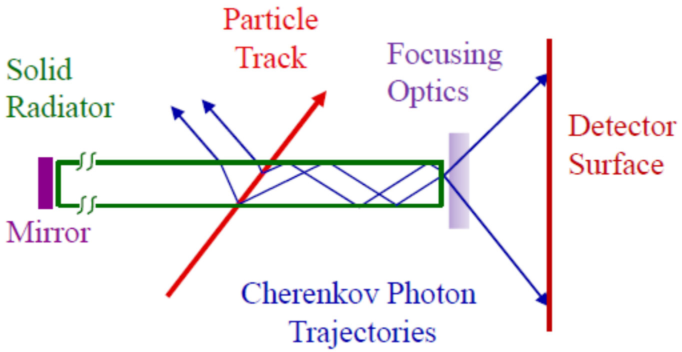
Outline

1. Motivation summary

2. Simulations

3. Hardware

DIRC principle



- Charged particle traversing radiator with refractive index n with $\beta = v/c > 1/n$ emits Cherenkov photons on cone with half opening angle $\cos\theta_c = 1/\beta n(\lambda)$.

- For $n>\sqrt{2}$ some photons are always totally internally reflected for $\beta\approx 1$ tracks.

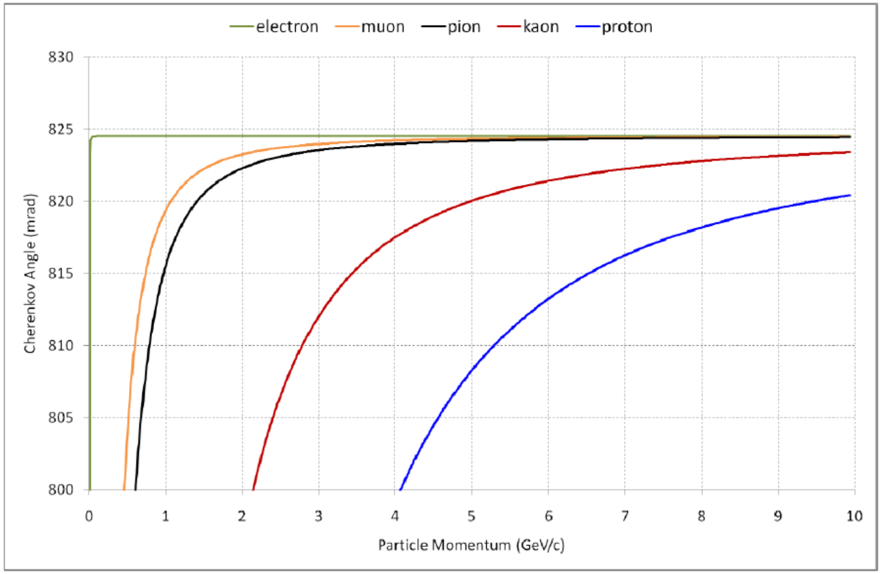
- Radiator and light guide: bar made from Synthetic Fused Silica

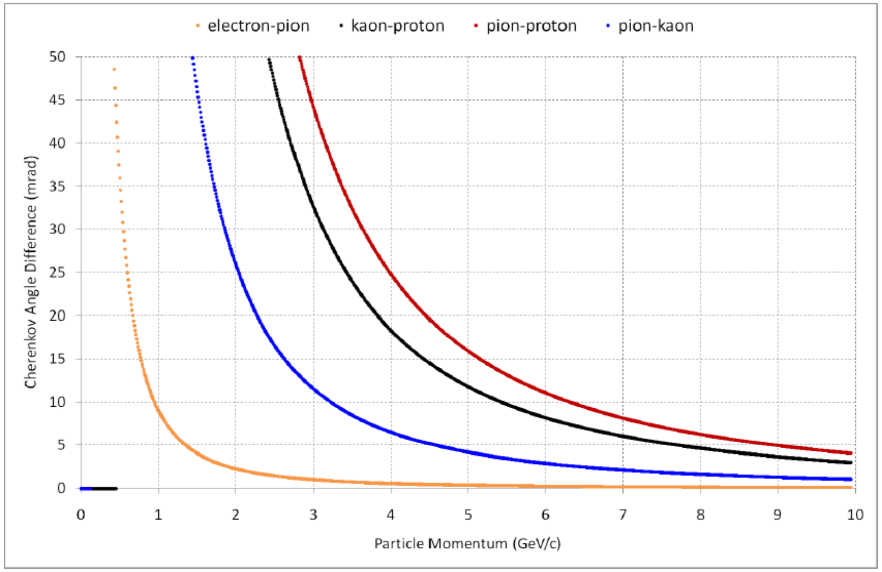
- Magnitude of Cherenkov angle conserved during internal reflections (provided optical surfaces are square, parallel, highly polished)

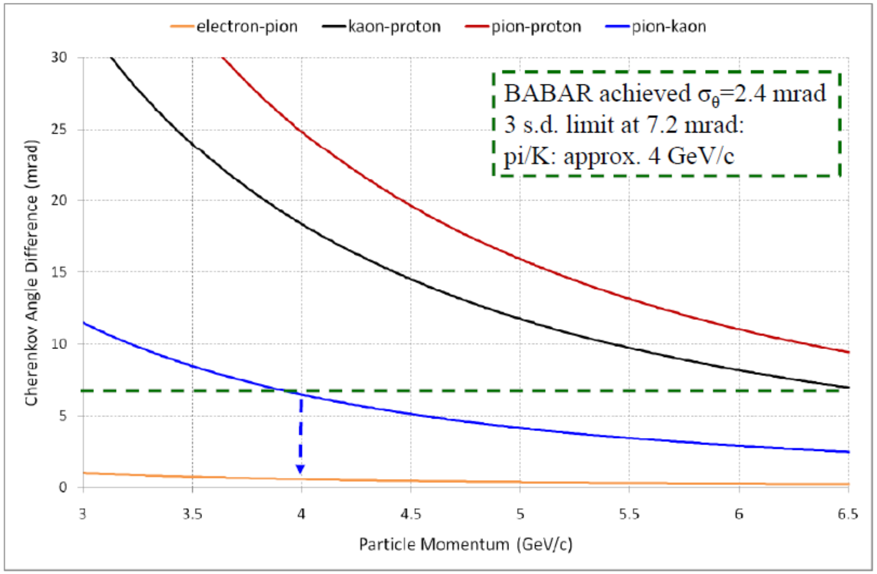
- Photons exit radiator into expansion region,
  detected on photon detector array.
  (pinhole imaging/camera obscura or focusing optics)

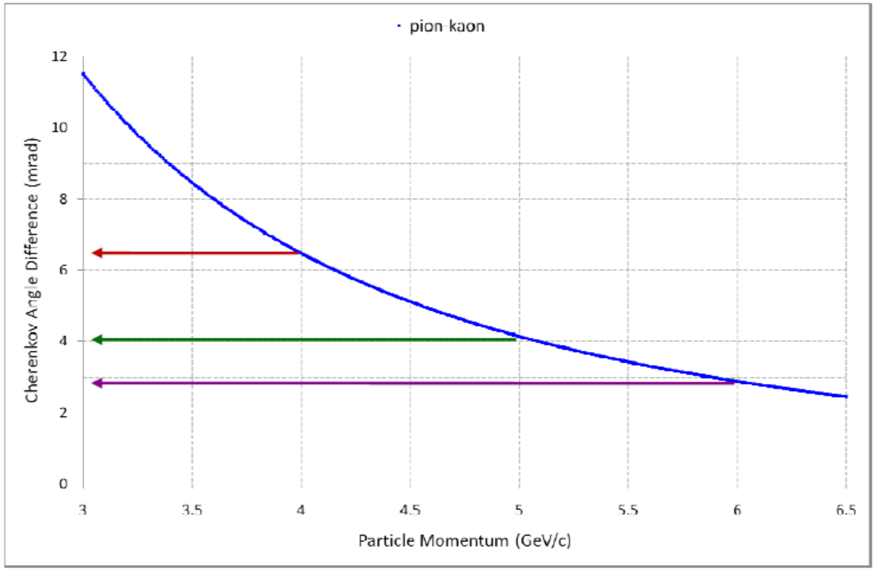
- DIRC is intrinsically a 3-D device, measuring: x, y, and time of Cherenkov photons, defining θ_c, ϕ_c, $t_{propagation}$ of each photon.

Momentum coverage and θ_c resolution



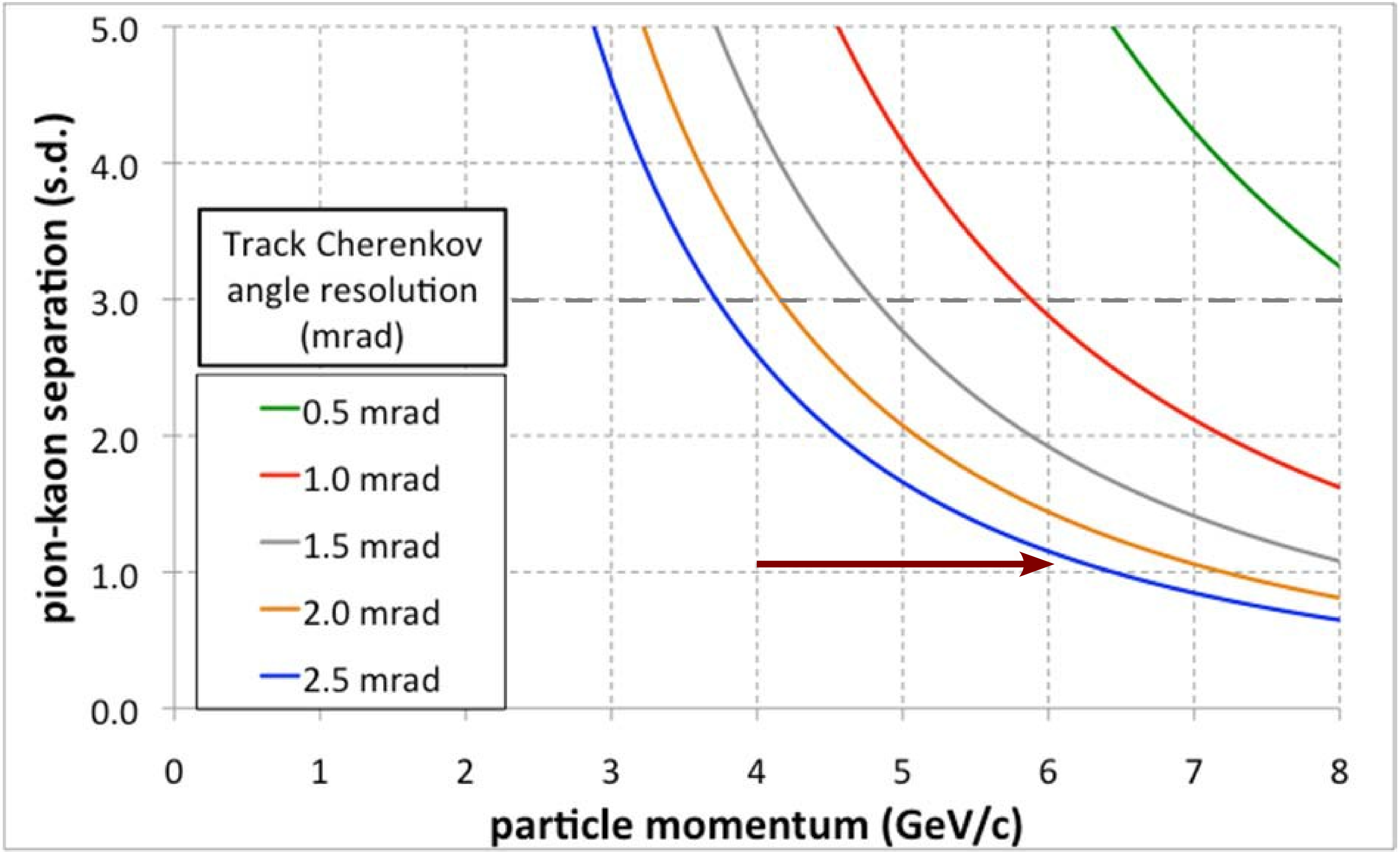






- Extending π/K separation from 4 to 6 GeV/c requires $\sigma_\theta \sim 1$ mrad (vs 2.4 in BaBar – a 58% reduction).

PID as a function of θ_c resolution



Improving the θ_c resolution

$$\sigma_{\theta_c}^{track} = \frac{\sigma_{\theta_c}^{photon}}{\sqrt{N_{p.e.}}} \otimes \sigma^{correlated}$$

Correlated term:
tracking detectors, multiple scattering, etc

$$\sigma_{\theta_c}^{photon} = \sqrt{\sigma_{bar-size}^2 + \sigma_{pixel-size}^2 + \sigma_{chromatic}^2 + \sigma_{bar-imperfection}^2}$$

BABAR-DIRC Cherenkov angle resolution: 9.6 mrad per photon → 2.4 mrad per track

Limited in BABAR by:			Could be improved via:
· size of bar image	~4.1 mrad	→	· focusing optics
· size of PMT pixel	~5.5 mrad	→	· smaller pixel size
· chromaticity ($n=n(\lambda)$)	~5.4 mrad	→	· better time resolution
	9.6 mrad	→	4-5 mrad (?) per photon
· number of photons	15-50	→	· photocathode/SiPM

topics for R&D proposal

- DIRC bar thickness can in principle also be increased beyond the 17 mm (19% r.l.) used in Babar
- Excellent 3D imaging (2 spatial + time) essential for pushing performance beyond state-of-the-art

Event reconstruction I

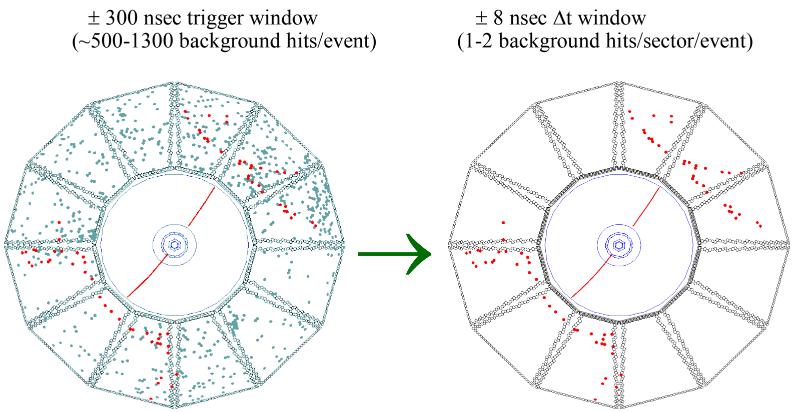
Calculate unbiased likelihood for signals to originate from e/μ/π/K/p track or from background:

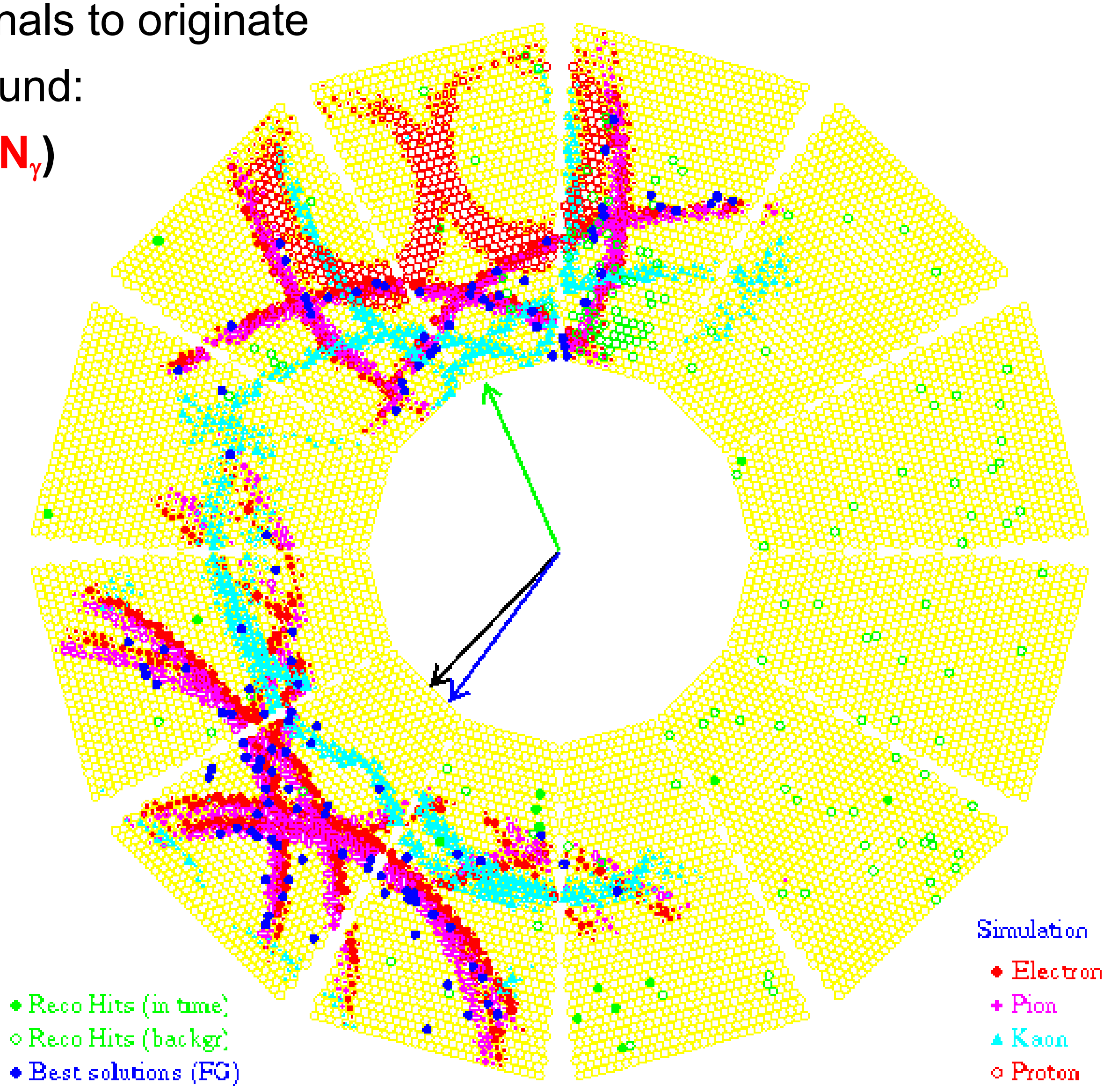
Likelihood: **Pdf(θ_c) ⊗ Pdf(Δt) ⊗ Pdf(N_γ)**

Pdf = Probability distribution function

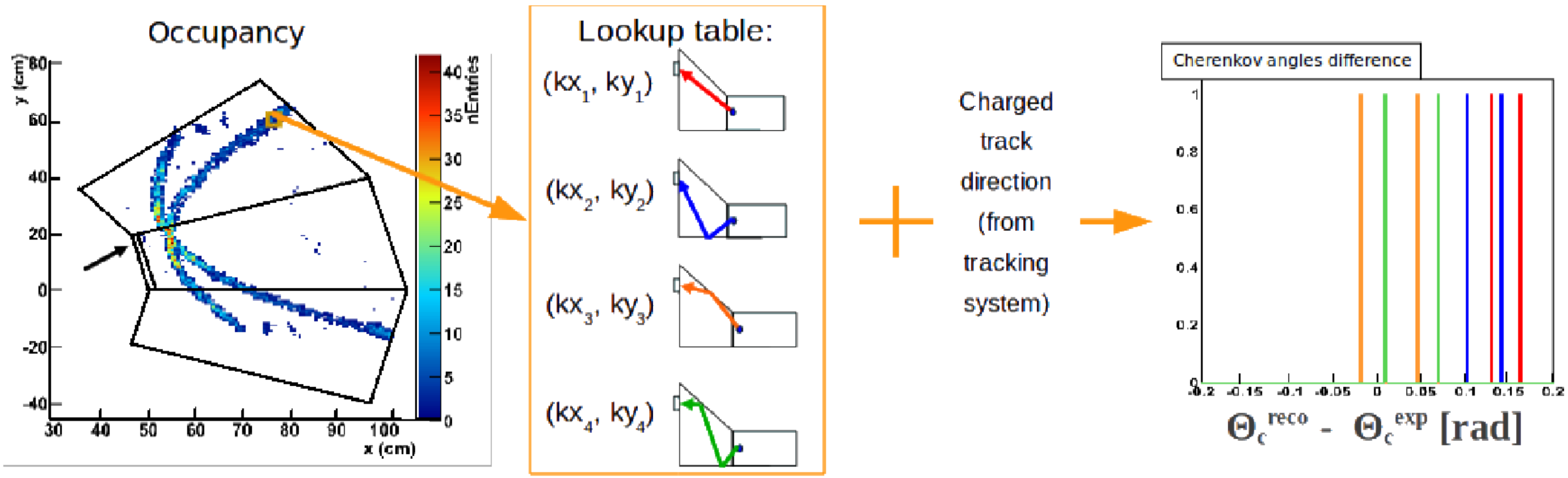
Example: comparison of real event to simulated response of BABAR DIRC to e/π/K/p.

Time resolution important for background suppression





Event reconstruction II



- For design purposes it is better to reconstruct the single-photon θ_c resolution and photon yield
- Can serve as figure of merit
- Will be used to quantify the impact of each design parameter

R&D goals

1. Demonstrate feasibility of using a DIRC in hermetic EIC detector

- Compact readout “camera” (expansion volume + sensors)
- Operation in high magnetic fields (up to 2-4 T)

2. Investigate possibility of pushing state-of-the-art performance

- Extend 3σ π/K separation beyond 4 GeV/c, maybe as high as 6 GeV/c
  - also improve e/π and K/p separation

3. Study integration of the DIRC with other detector systems

- Supplementary gas Cherenkov?
- Integration with solenoid, tracking, calorimeter, etc
- Accelerator backgrounds (in collaboration with SLAC)

Important Events

Postdoc (H. Seraydaryan) was hired at ODU in November 2011

- Currently working 50% on DIRC simulations and reconstruction

Collaboration meeting at JLab, March 23 – 29, 2012

- Full participation
- A strategy for simulation and expansion volume design was laid out

Travel to GSI, May 20 – June 3, 2012

- This Sunday H. Seraydaryan is going to GSI for two weeks
- The primary goals of the visit are to set up the event reconstruction, work on the simulations, and familiarize her with the test setup at GSI.

Design Strategies

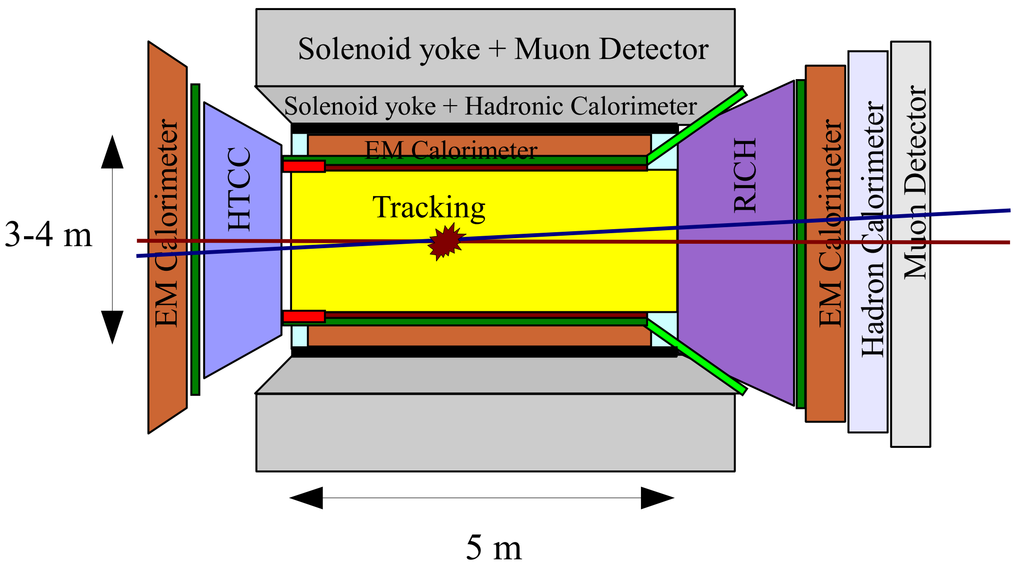
1. Expansion volume and sensors outside of the endcap

- Suggested by the Advisory Committee
- Requires longer bars
  - Good for chromatic correction via fast timing (longer path)
- Many bounces → wide radiator bars preferred (= plates, one per box)
  - Lower bar cost (50% - 75%)
  - Requires new event reconstruction methods (synergies with work for PANDA)
- Less constrained expansion volume geometry
  - Mirror focusing in solid fused silica blocks as in SuperB
  - Sensors in lower B-fields

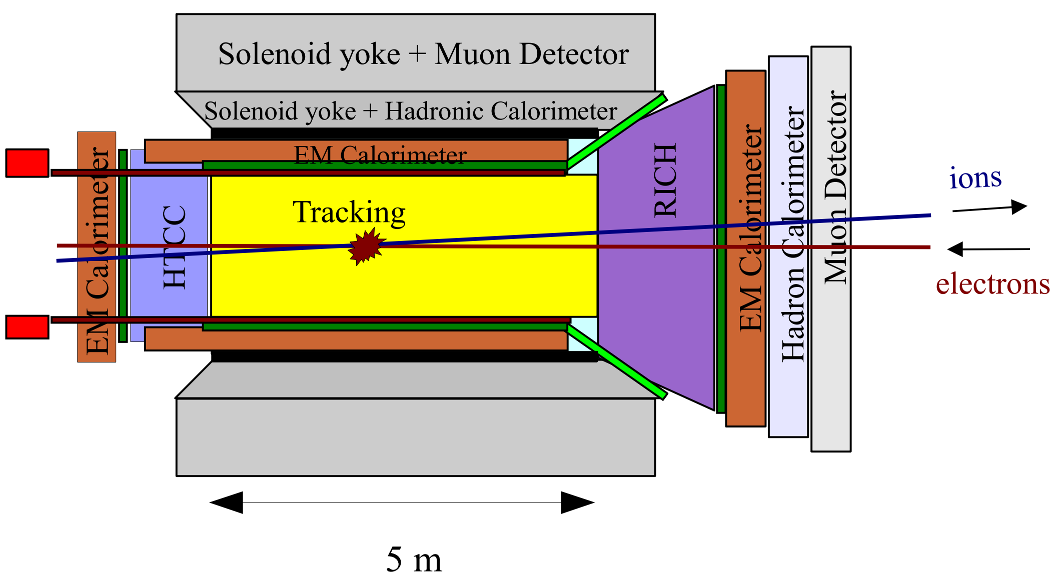
2. Expansion volume and sensors inside solenoid

- Need compact expansion volume
  - Will explore focusing with both mirrors and lenses
- Conventional (BaBar-like) radiator bars
  - Well understood reconstruction
  - Good for proof of concept

Detector integration: high-performance DIRC



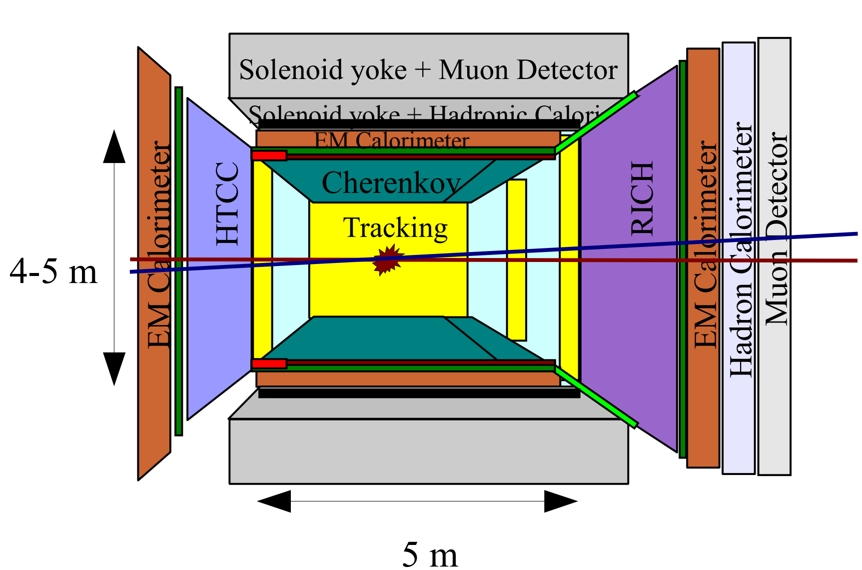
- TOF
- DIRC bar
- DIRC expansion volume



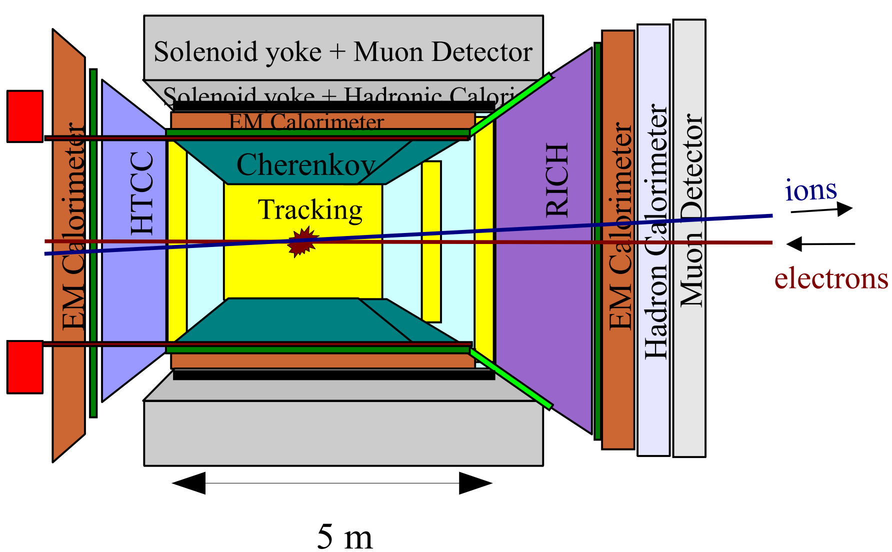
- A DIRC-only PID solution in the barrel could be relatively easily adapted to placement of the EV outside.

- The DIRC bars/plates would be quite long in this configuration

Detector integration: DIRC + threshold Cherenkov



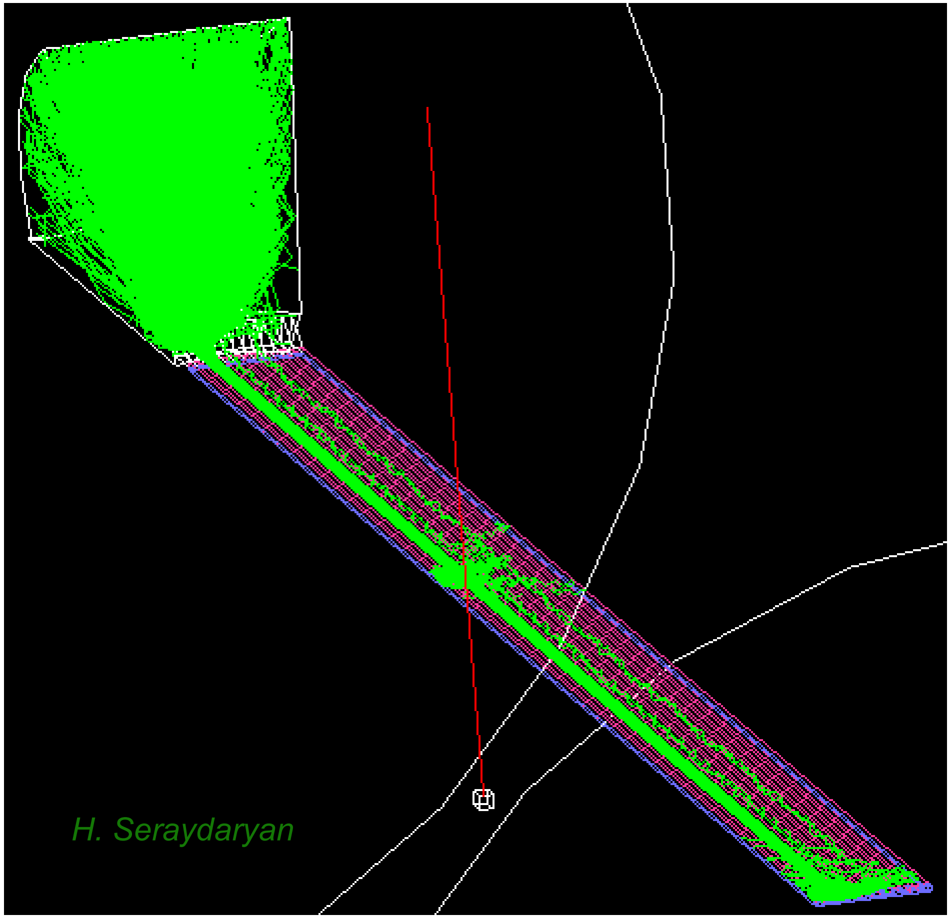
- TOF
- DIRC bar
- DIRC expansion volume



- A detector configuration using a supplementary Cherenkov would not be as easy to adapt to placing of the EV outside.

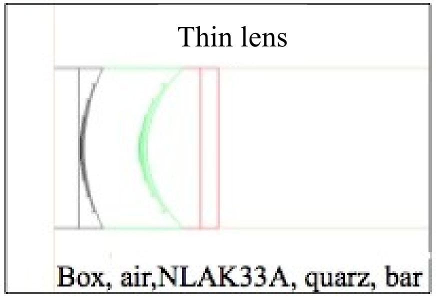
DIRC simulations and EV design

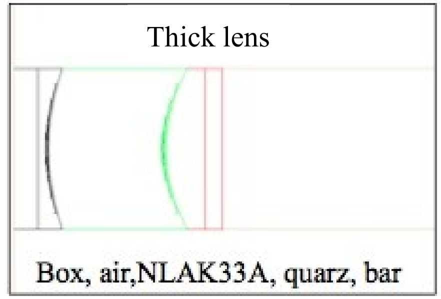
- Ray-tracing software (DRCPROP) will be used for parameter studies and the initial design of the EV
- Detailed studies of the selected EV design will be performed using GEANT4
- This can then be implemented into the GEANT4 (GEMC) framework used for the EIC detector
  - Integration studies

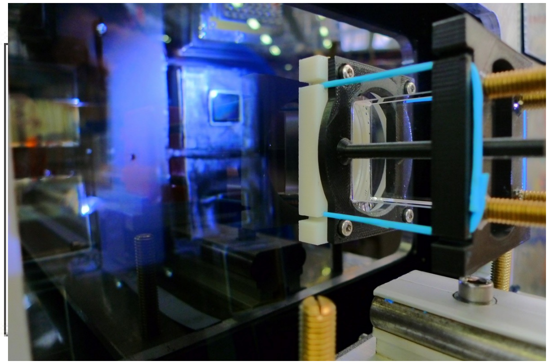


First tests of implementing a DIRC into GEANT4 at ODU/JLab using the BaBar geometry

Simulations using lenses with air gap



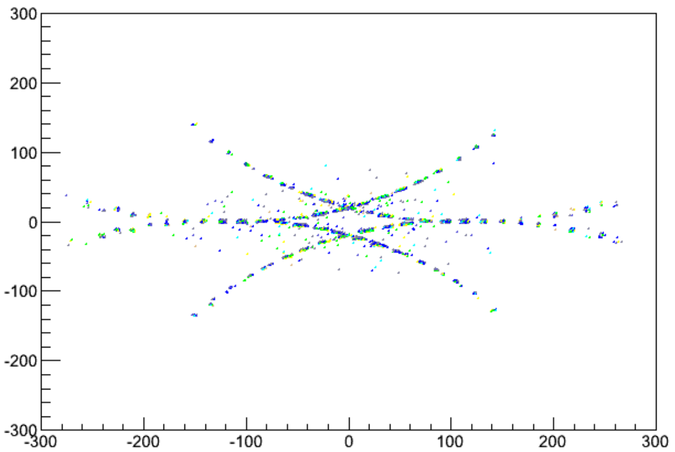




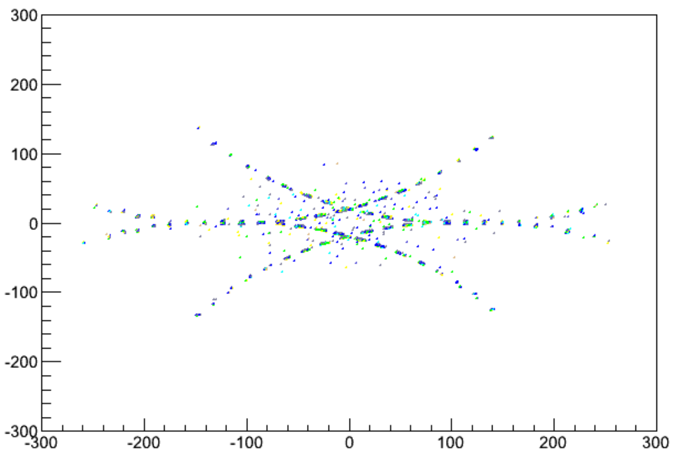
PANDA prototype with lens

$\beta = 0.99$, $\theta = 50°$, $\varphi = 70°$

Thin lens focussed



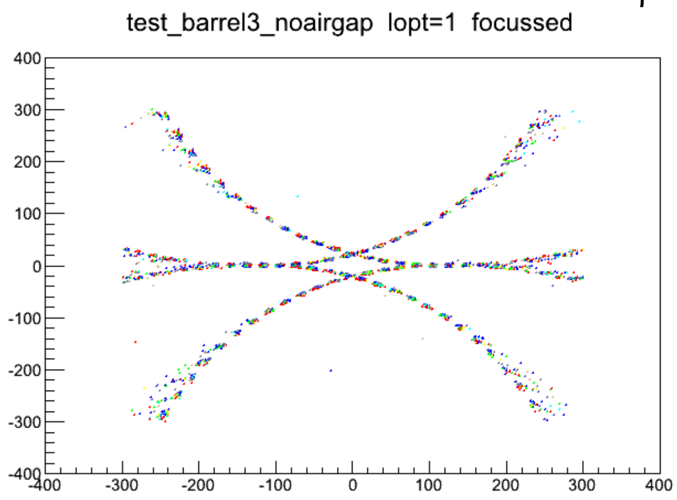
Thick lens focussed

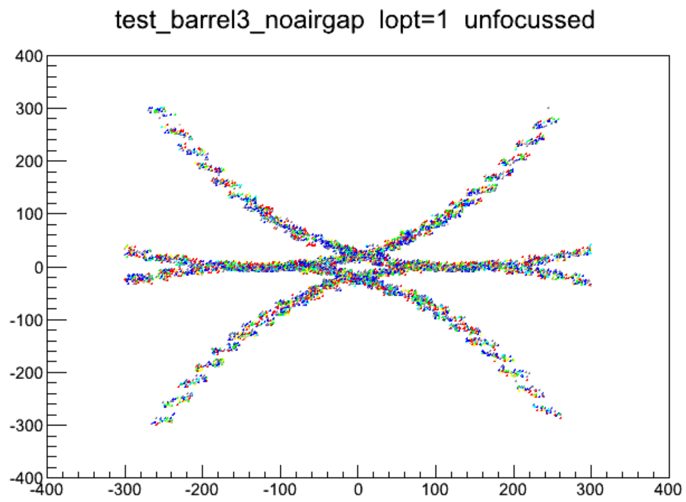


- Lenses with an air gap provide a sharp image
- Photon losses due to internal reflection for some track angles.

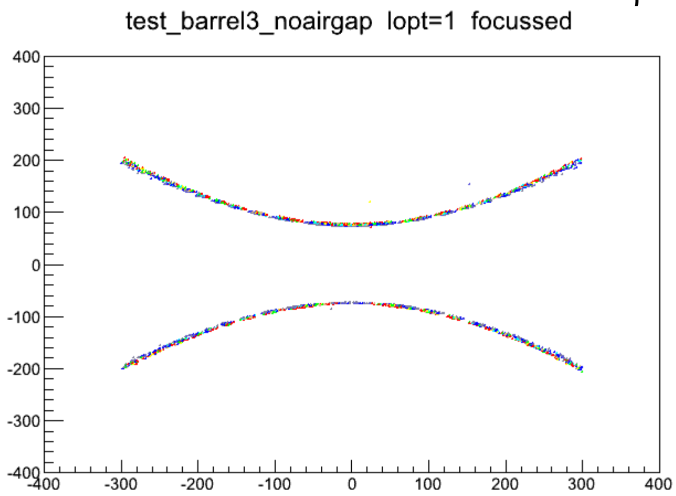
First simulations of new lens without air gap

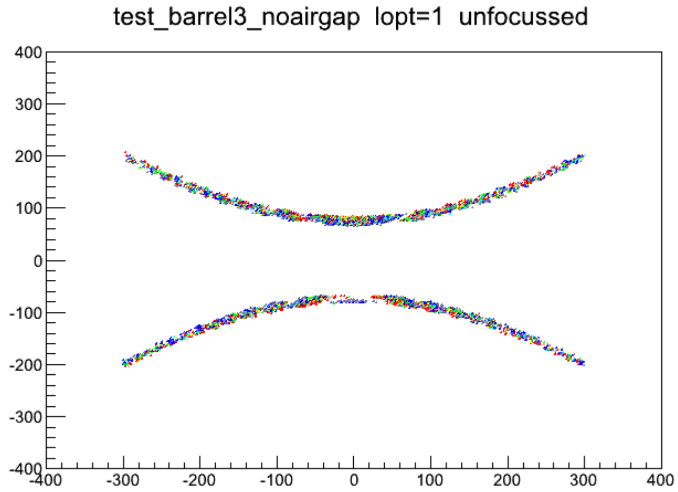
$\beta = 0.99$, $\theta = 50°$, $\varphi = 70°$





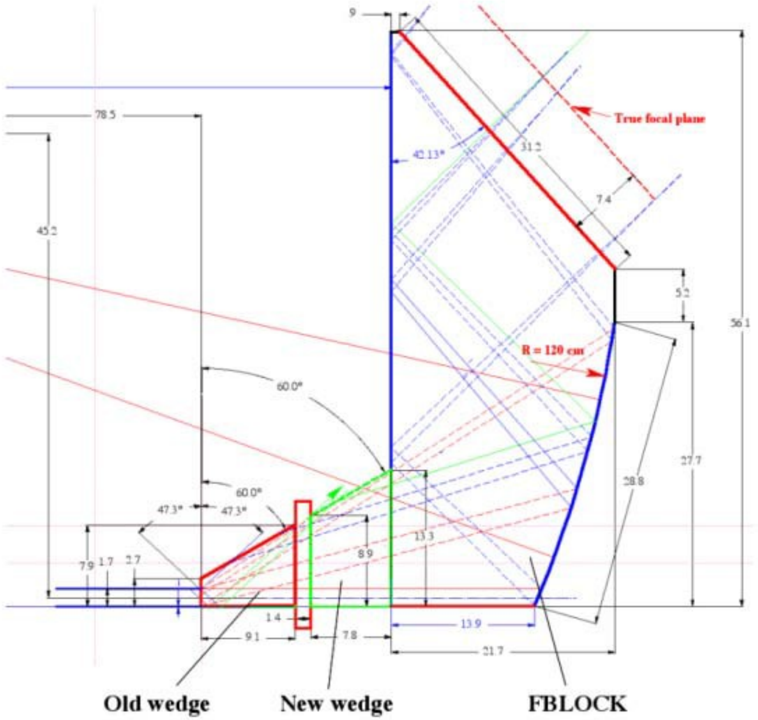
$\beta = 0.99$, $\theta = 60°$, $\varphi = 90°$



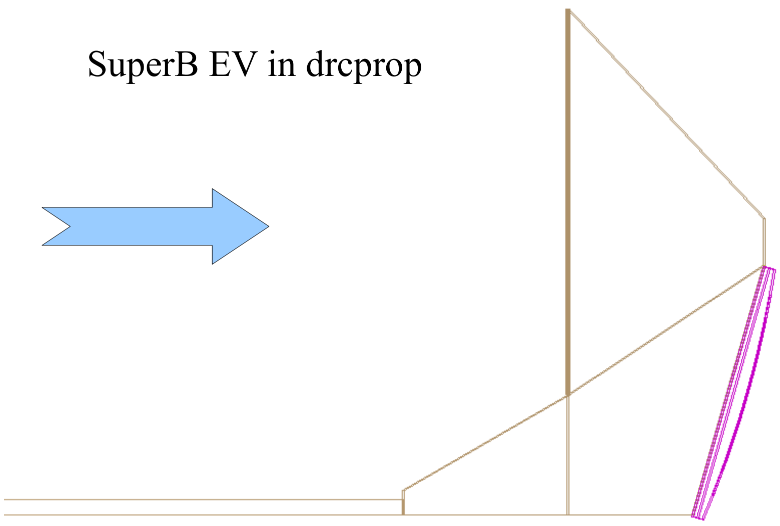


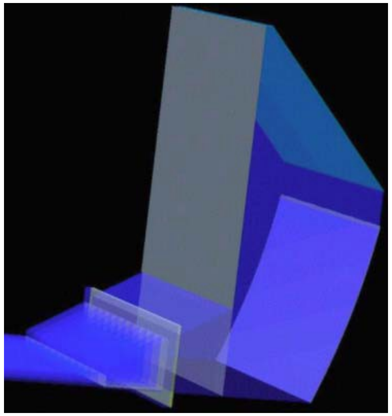
- High-n lenses and antireflective coatings can reduce photon losses

SuperB EV design as starting point with mirrors



SuperB EV in drcprop

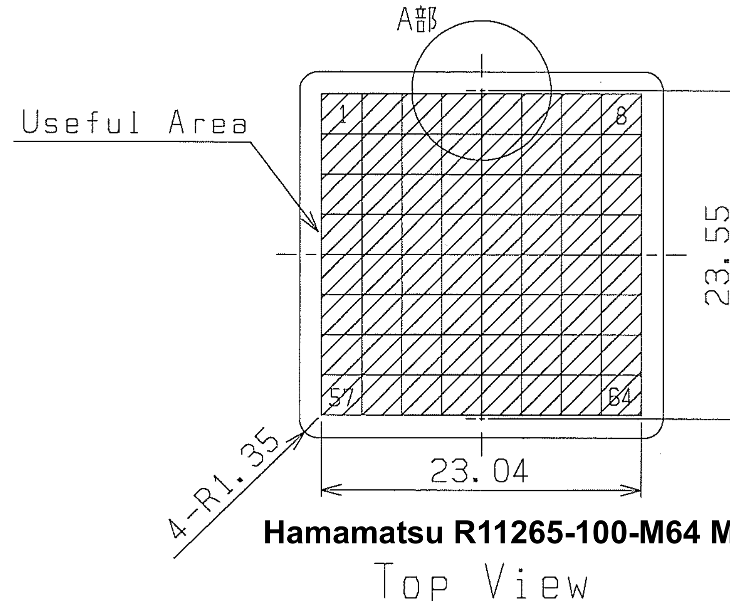




- SuperB mirror optics have been implemented in drcprop
- Will be modified to fit EIC requirements
- Simulations will start soon

Procurement of sensors

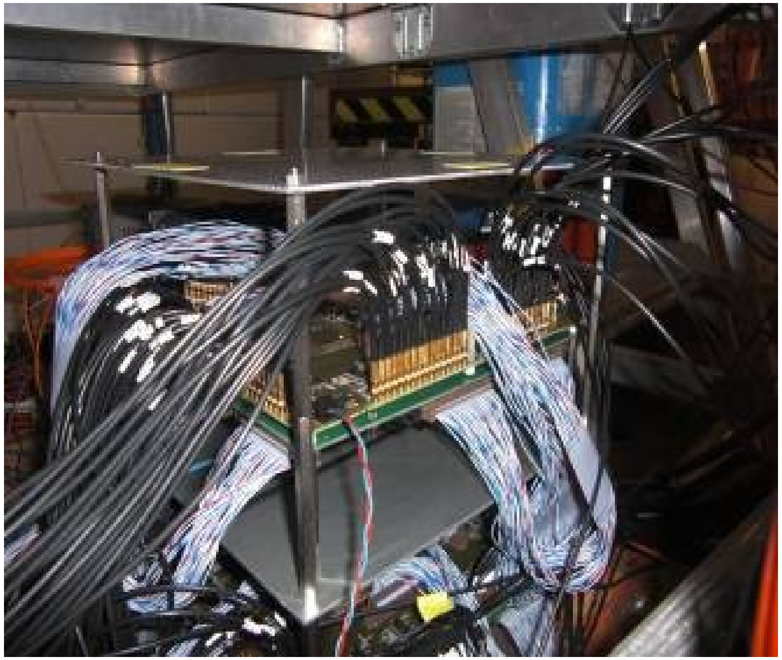
Hamamatsu 9500 MaPMT
16x16 channels, $8.5k



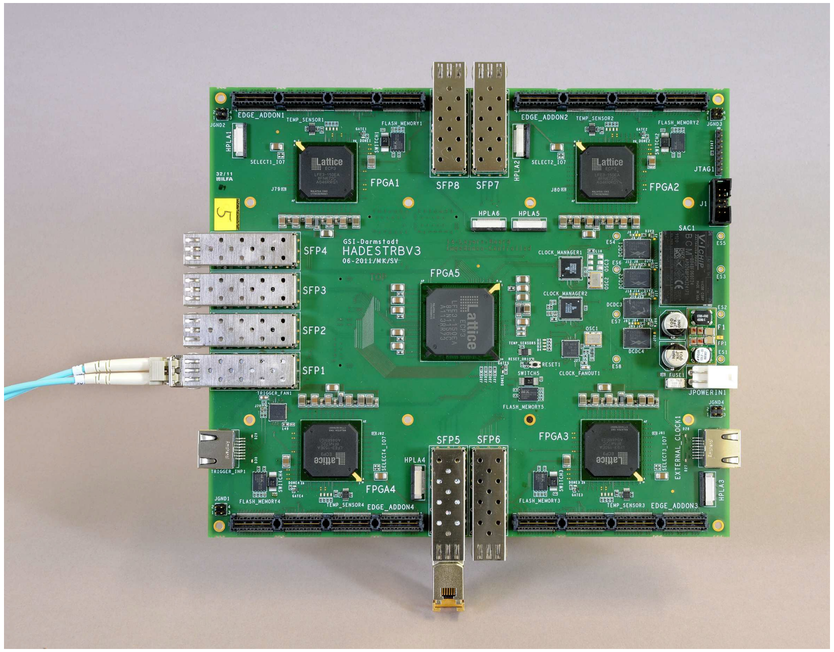
Hamamatsu R11265-100-M64 MaPMT
8x8 channels, $2.5k

- Have received quotes from Hamamatsu for the 9500 and the newer R11265 Multi-anode PMTs
  - Both have pixel size of about 3 mm
  - Will be used for studies of focusing optics
- Contacted BINP regarding planned purchase of their round MCP-PMT for B-field studies
  - Currently not available with sufficiently good single-photon properties
  - Similar Photoek model is much more expensive (20k Euro)
  - Will postpone purchase until needed for tests at the new facility in year 2

Procurement of DAQ



HADES TRBv2 readout system



Actual TRBv3 board. Size is 20 x 23 cm.

- EIC setup will use the new HADES TRBv3
  - Expected to be available this summer
- New version can still take advantage of DAQ infrastructure used for PANDA DIRC
- Procurement will soon be initiated
  - Preparations already under way at GSI

Summary

Simulations of expansion volume is on track

- Tools are in place
- Simulation strategy has been agreed on at collaboration meeting
- Simulations of lens-based optics are in progress
- Simulations of mirror-based optics will begin shortly

Hardware procurement

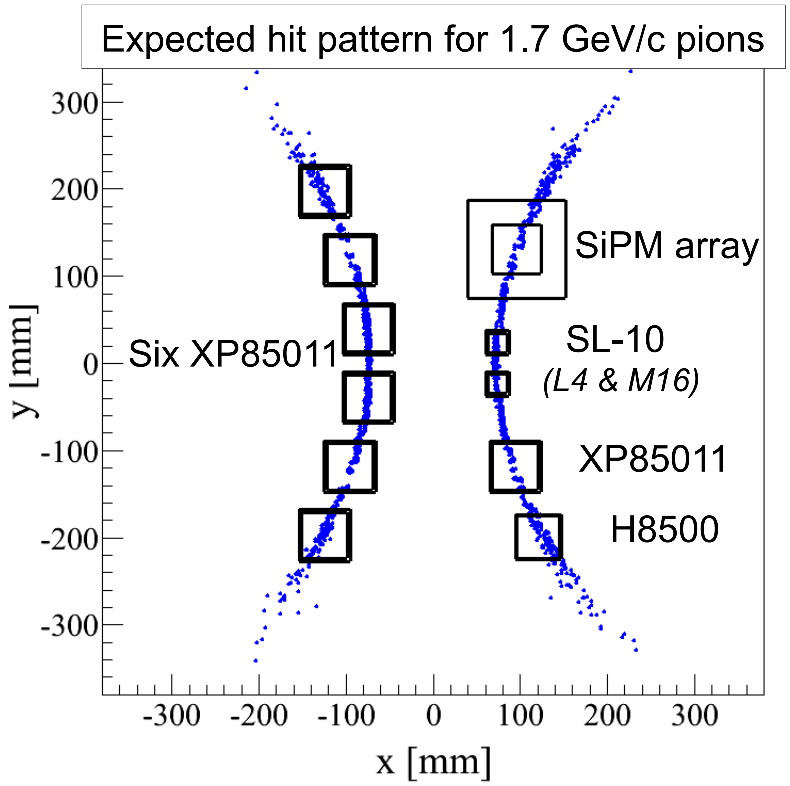
- Generally on track
- Some delays with sensor procurement will not affect schedule

Travel funds spent

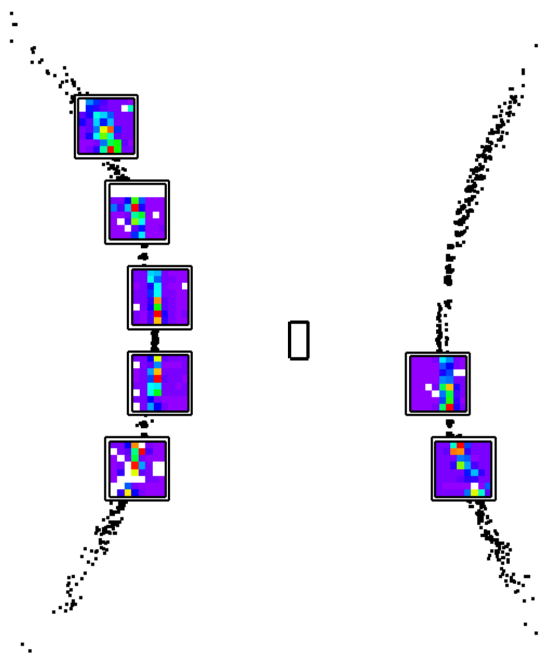
- Close transatlantic collaboration!

Backup

PANDA: results from 2011 tests at CERN



Simulation



Data

Primary responsibilities

1. Simulations of DIRC performance and design of EV prototype

- Old Dominon University

2. Integration with the EIC detector

- Catholic University of America

3. Prototyping and hardware test (except high magnetic fields)

- GSI (Helmholtzzentrum für Schwerionenforschung)

4. Sensor test in high magnetic fields

- University of South Carolina and Jefferson Lab

Note: **The proposal is a collaborative effort and most institutions will contribute to more than one of the areas above regardless of their primary responsibility**

Funding Request for FY12 (and FY13)

Budget	FY11	FY12	FY13	*Total*
Postdoc (50%)	$53,290	$54,000	$55,000	*$162,290*
Students	$8,300	$13,764	$13,764	*$35,828*
Hardware	$41,970	$58,630	$57,200	*$157,800*
Travel	$11,440	$13,606	$14,036	*$39,082*
Total	*$115,000*	*$140,000*	*$140,000*	*$395,000*

The salaries for the postdoc and students include university overhead. Matching funds are available for the postdoc. The travel includes JLab or USC overhead. Hardware includes JLab or CUA overhead.

Budget	FY11	FY12	FY13	*Total*
Old Dominon Univesity (ODU)	$53,290	$54,000	$55,000	*$162,290*
Catholic University of America (CUA)	$9,800	$8,300	$8,300	*$26,400*
University of South Carolina (USC)		$7,606	$7,606	*$15,212*
JLab and GSI (through MoU)	$51,910	$70,094	$69,094	*$191,098*
Total	*$115,000*	*$140,000*	*$140,000*	*$140,000*

Deliverables

Year 1 – requirements, simulations, simple EV prototype

1. Initial e/π identification requirements for the central EIC detector.
2. Simulation and reconstruction framework for DIRC prototype.
3. DIRC resolution studies and design of prototype.
4. Compact expansion volume prototype with multi-pixel readout.
5. DAQ system tested using laser pulser.

Year 2 – integration with EIC and design of final prototype

1. Integration of a DIRC into the EIC detector.
2. Performance plots for EIC DIRC.
3. Design for final prototype EV.
4. Test of sensor response at 2-4 T magnetic field.
5. Cherenkov ring resolution in test beam (if available).

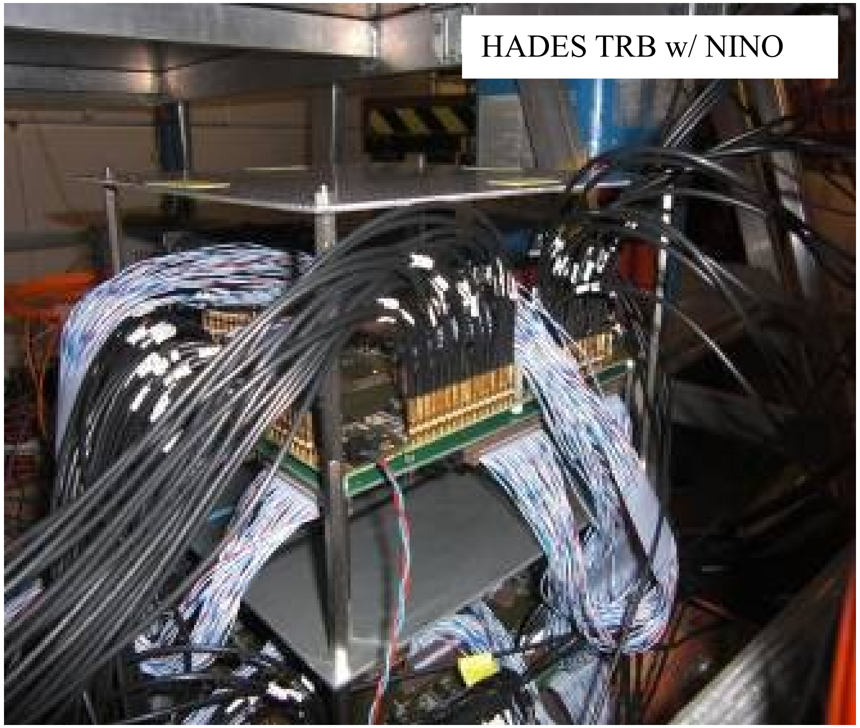
Year 3 – tests with final "camera" prototype

1. Performance parameters of DIRC in the EIC detector.
2. In-beam test of compact EV (if available)
3. Comparison of photon yield for different multi-pixel sensors
4. Determination of Cherenkov angle resolution of final prototype EV

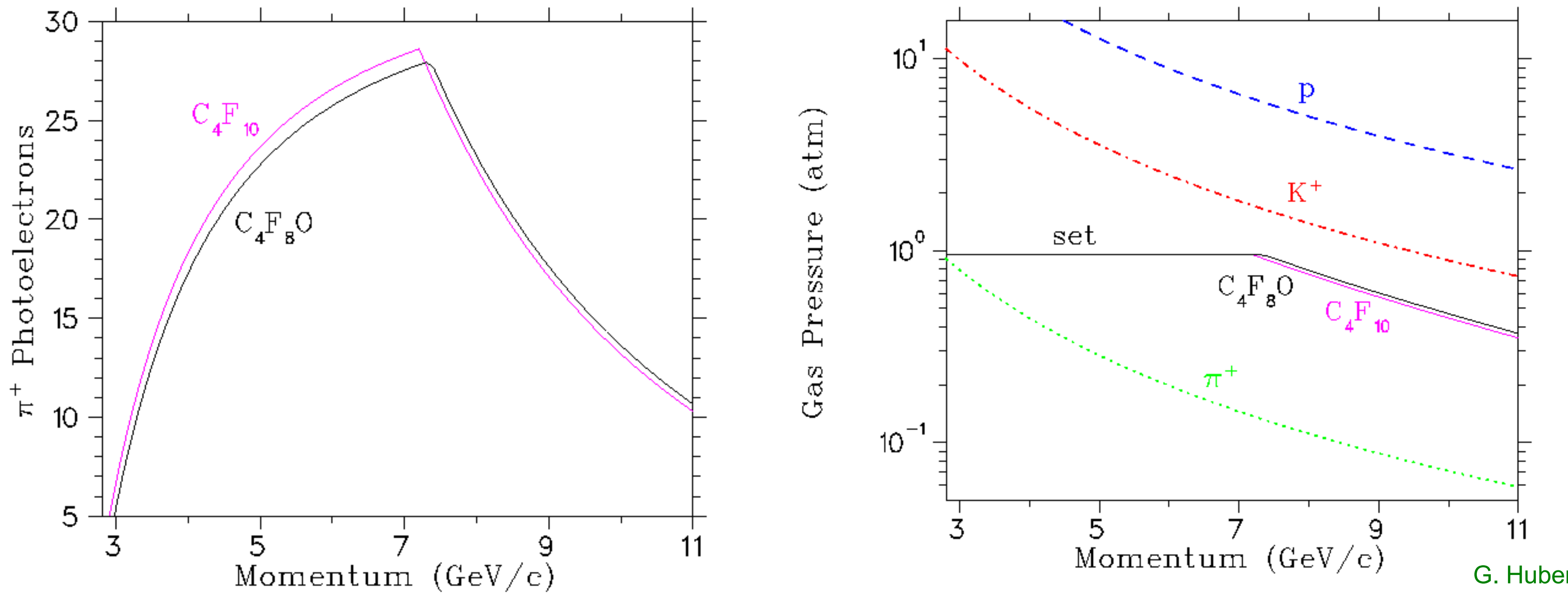
PANDA: Barrel DIRC Readout Electronics

Electronics design demanding

- Signal rise time typically few hundred picoseconds.
- 10-100x preamplifier usually needed.
- High bandwidth 500MHz – few GHz (optimum bandwidth not obvious).
- Pulse height information required for < 100 ps timing (time walk correction),
  and desirable for 100-200 ps timing (ADC / time over threshold / waveform sampling / ...)
- PANDA will run trigger-less.
- Large data volume (Disk: up to 200 Gb/s).
- Example:
  HADES TRB board with NINO TOF add-on in GSI test beam in 2009, updated TOF add-on in test beams at GSI (next week) and at CERN in July.
- Significant development effort ahead.
- dSiPM with digitization on chip – no TDC, preamp, ADC, etc development required.



Supplementary threshold Cherenkov detector



Number of p.e. in 60 cm of gas (left), and threshold as function of gas pressure (right)

- If needed, a supplementary threshold Cherenkov can provide
  - e/π separation for 1-3 GeV/c
  - π/K separatation for 4-9 GeV/c (higher with some underpressure)
- A radiator thickness of 60 cm (+ 10 cm for readout ?) is clearly adequate, 40 cm may be sufficient
- C_4F_{10} gas can be replaced by the more eco friendly C_4F_8O